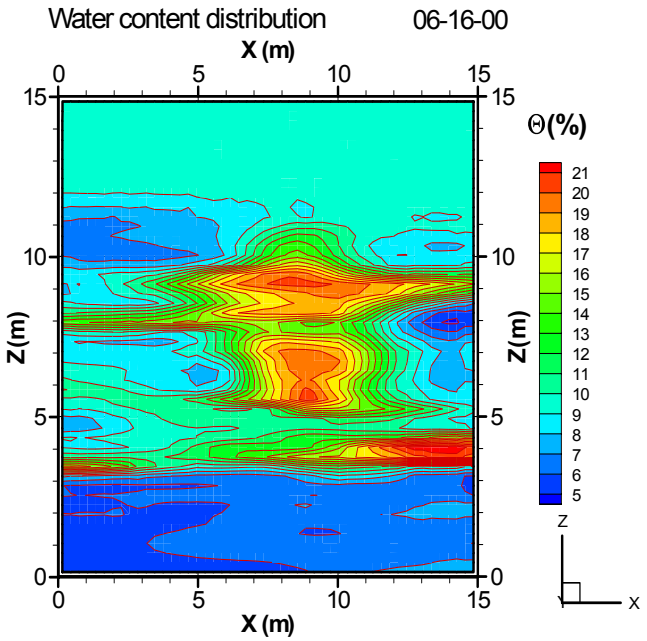
# APPLIED STOCHASTIC SUBSURFACE HYDROLOGY & ENVIRONMENTAL GEOPHYSICS




**A Short Course By**

Department of Hydrology and Water Resources

***The University of Arizona***
*Tucson, Arizona*

**March 16 - 19, 2004**

## WHY ATTEND THIS COURSE?

**Because:**

1. Deterministic answers to real-world environmental problems are not enough anymore. More regulators and studies involved in litigation are *requiring* the **uncertainty** associated with an estimate to be quantified along with the values of the parameters of interest.

2. Simple fully saturated flow models, which ignore or vastly simplify artificial recharge and infiltration through the vadose zone are inadequate, especially when spatial or temporal changes in recharge and properties impact results. The aquifer system as an entire, **variably saturated** continuum is now possible, and should be done whenever possible.

3. Larger and more detailed models of multi-dimensional domains require **more data** to calibrate; *point* measurements of pressure and concentration typically do not constrain inverse solutions adequately, **surface** and **borehole hydrogeophysics** should be used to bring additional understanding to problems 2 and 3-D problems.

4. Bringing together all this new data, and new understanding into a 3-D model, can lead to *data overload*. **Geostatistics** and **stochastic fusion** are two powerful ways in which data can be diverse date types can be integrated.

## COURSE INFORMATION

We will begin with the fundamental concepts of flow through porous media and then cover the general governing equations for flow through variably saturated (either fully or partially saturated) geological media. Properties of variably saturated media and the sensitivity of numerical solutions to them are introduced and examples are used to illustrate their importance.

The necessary and sufficient conditions for well-posed inverse problems, in variably saturated media, are discussed in relation to the proper design of field and laboratory experiments.

A structured and systematic model calibration methodology is presented, which can be used to ease calibration efforts, while obtaining a realistic inverse solution, even for "ill-posed" problems.

Stochastic methods developed during the last two decades for solving heterogeneity problems will be taught in an easy-to-understand fashion and will be applied to model calibration.

The use of geostatistical analysis, including variogram analysis and kriging, for the delineation of spatial parameter and measured responses distributions is covered. Geostatistics can be used as a tool to assist in fine-tuning hydraulic properties for input and while quantify their uncertainty.

Both the theory behind and practical use of state-of-the-art hydrogeophysical surveys are presented, for site characterization and the monitoring of site conditions through time.

The course also includes a two days of hands-on computer model calibration using principles and knowledge discussed in the lectures. A graphic user interface named VSAFT2®, which has been developed to simply the setup of model input files, for simulating two-dimensional flow and chemically reactive solute transport is introduced. The model and user interface is available free to participants.

Real-world data sets from Avra Valley, Arizona will be used for saturated flow model calibrations while data collected from experiments in Hanford, Washington will be used as an exercise for unsaturated flow model calibration. These modeling exercises also will include development of animations of observed and simulated time evolutions of pressure head, and moisture plumes along with 3-D iso-surface plots. We will show how these plots can assist model calibrations.

## WHO SHOULD ATTEND

Many types of people will find the information in this course useful, including hydrologists, hydrogeologists, geologists, soil scientists, environmental engineers, geophysists, graduate students and other professionals or interested persons working in the area of water resources. Decision makers and planners in environmental and earth sciences would gain understanding as well. Participants are expected to have some knowledge of subsurface hydrology, to be familiar with Windows 2000® or Windows XP® and some previous exposure to numerical modeling is definitely a plus.

## SCHEDULE

**March 16 - 19, 2004**

Courses will commence each day at 8:00 AM and will end by 5:00 PM.

## WHERE

This course will be held at the University of Arizona in Tucson, Arizona. Weather during March is warm and pleasant. The average daily maximum temperature is 80°F with low humidity. Several public recreational facilities, including public golf courses are nearby the campus.

## COURSE OUTLINE

### 1 - BASIC CONCEPTS OF FLOW THROUGH POROUS MEDIA

Conceptual models of flow in variably saturated porous media;
Physical properties of water and geological media;
Hydraulic, pressure and elevation heads;
Soil-moisture characteristic curve;
Unsaturated hydraulic conductivity, hysteresis, anisotropy.

### 2 - STOCHASTIC REPRESENTATION OF HETEROGENEITY

Probability distribution, stochastic processes, ensemble, ergodicity, second order stationarity;
Mean, auto-covariances, cross-covariance;
Variograms, intrinsic hypothesis, theoretical variogram models;
Stochastic representation of heterogeneity, generation of synthetic heterogeneous hydraulic property fields.

### 3 - FORWARD MODELING

Modeling transient and steady flow in homogeneous and heterogeneous aquifers;
Modeling transient and steady flow in homogeneous and heterogeneous variably saturated media.

### 4 - INVERSE MODELING

Necessary and sufficient conditions for inverse problems to be well-posed for saturated flow and unsaturated flow;
Stochastic conceptualization of inverse problems;
Stochastic formulae for upscaling saturated and unsaturated hydraulic properties;
Parameter estimations using Kriging;
A structured approach for calibrating flow through variably saturated geological formation.

### 5 - GEOPHYSICAL MONITORING & CHARACTERIZATION

Seismic reflection survey, potential methods, electrical and electromagnetic methods, ground penetrating radar, and bore-hole geophysics.

## INSTRUCTORS

**Jeffery Daniels**

Dr. Daniels is a Professor in the Department of Geological Sciences and Associate Dean for Research in the College of Mathematical and Physical Sciences. He received his Ph.D. in Geophysical Engineering from the Colorado School of Mines. He has participated in numerous professional panels (e.g., CIC Leadership Forum, Science Advisory Board for the Strategic Environmental Research and Development Program for the DOD). He is also a consultant to the DOE on several waste cleanup projects and programs. Prior to 1985, he was a research scientist for the U.S. Geological Survey in Denver, Colorado working on surface electrical methods and borehole geophysical methods (electrical, nuclear, and acoustic) for characterizing physical properties near the borehole. His most recent theoretical research has focused on the development of stochastic approaches to 3D modeling (forward and inverse) of geophysical data, and fusion of hydrologic and geophysical models in soils and the zone of percolation above the water table. He has worked on sensor development projects for GPR, testing of electrical methods for soil moisture determination for agricultural applications, and the development of EMI and GPR models.
http://www.geology.ohio-state.edu/~jeff

**Susan Hubbard**

Susan Hubbard is a staff scientist in the Earth Science Division of Lawrence Berkeley National Laboratory. Her educational background includes a B.S. in geology from UC Santa Barbara, a M.S. in geophysics from Virginia Tech, and a Ph.D. in Groundwater from the Civil and Environmental Engineering Department of UC Berkeley. She has worked as a geologist for the USGS and as an exploration geophysicist within the petroleum industry.

Susan's research interests focus on the combined use of hydrogeological and geophysical data for improved understanding of subsurface parameters and processes.

Her current projects focus on environmental, precision agricultural and ecological studies. Susan serves as: an Associate Editor for Water Resources Research, the United States representative for the International Association of Hydrological Sciences 2020 Working Group, the chair of the AGU Hydrogeophysics Technical Committee, and as a co-editor for the first Hydrogeophysics textbook, which will be published by Kluwer in 2004. She is a member of AGU, SEG, EEGS, and IAHS. For publications and more information, please visit:
http://esd.lbl.gov/people/shubbard/vita/webpage/hubbard_cv.htm

**Raz Kahleel**

Dr. Raz Khaleel is a consulting environmental engineer with Fluor Federal Services, Richland, WA. He has over 30 years of consulting, teaching and research experience in subsurface and surface hydrology and numerical modeling. He received his B.S. in Civil Engineering from Bangladesh University

of Engineering and Technology, M.S. in Water Science and Engineering from Asian Institute of Technology in Bangkok, and Ph.D. in Soil and Water Engineering from Texas A&M University. He served on the academia at North Carolina State University at Raleigh, New Mexico Institute of Mining and Technology at Socorro and the University of Roorkee in India.

Currently, he is a member of the graduate faculty and an adjunct professor at Washington State University in Richland. At the U.S. Department of Energy Hanford site in Washington State, he has been working on a variety of environmental and waste management problems for the last 17 years. He has authored and coauthored over 30 journal articles.

**T.-C. Jim Yeh**
Dr. Yeh is a Professor in the Department of Hydrology and Water Resources, the University of Arizona. He received his B.S. in Geology from the College of Chinese Culture, Taiwan, his M.S. in Geological Sciences from the University of Illinois at Chicago, and his Ph.D. in Hydrology from the New Mexico Institute of Mining and Technology. He has extensive experience in numerical and stochastic analysis, and field and laboratory investigation of flow and transport in heterogeneous geological formations under variably saturated conditions. His current research focuses on the development of hydro/geophysical joint inversion techniques for cost-effective characterization and monitoring of the vadose zone and aquifers.
http://tian.hwr.arizona.edu/yeh

## ENROLLMENT

Enrollment is limited to 30. Registrations will be accepted in the order of payment. The registration fee for this course is $2,000 US, which includes lecture notes, VSAFT2, refreshments, and four luncheons. To register for this course, send a $100 US deposit in the form of a check or money order along with the registration form attached to this brochure. Full payment will be required upon arrival on the first day of the course. Deposits will be refunded provided notification is received at least four weeks prior to the course date. A substitute attendee may be designated if notification is given. Deadline for registration is February 12**,** 2004. We reserve the right to cancel the short course and notification will be given before February 16, 2004 if the course is to be cancelled.

## ACCOMMODATIONS

Participants are required to arrange their own accommodations. Thirty rooms have been set aside at Four Points by Sheraton Tucson University Plaza, 1900 E. Speedway Boulevard, and may be reserved by calling (520)327-7341 or (800) 325-3535 prior to February 15, 2004. After this date, availability of accommodations and rates cannot be guaranteed.

Please specify if you are an "Applied Stochastic Subsurface Hydrology & Environmental Geophysics" short course participant to receive the discounted room rate of $94 US for either single or double. Transportation to campus will be provided at 7:30 A.M. from the hotel.

## QUESTIONS ?

**Dr. Jim Yeh**
Dept of Hydrology & Water Resources
P.O. Box 210011
University of Arizona, Tucson, AZ 85721
Phone: (520) 621-5943
Fax: (520) 621-1422
yeh@hwr.arizona.edu

## SOFTWARE

**VSAFT2** is a finite element program for solving flow and reactive solute transport in variably saturated porous media (2-D horizontal plane, vertical plane, or axisymmetrical plane). It solves the modified Richards equation for variably saturated media either in a mixed form using the Newton-Raphson iteration scheme or pressure-based form using the Picard iteration scheme. It considers moisture-dependent anisotropy in the unsaturated hydraulic conductivity function and solves steady flow problems directly. It incorporates unique features to facilitate convergence of solutions for either steady or transient flow problems. The modified method of characteristics is used to solve the solute transport equations as such pure convective transport can be simulated. A friendly graphical user interface has been developed for easy generation of irregular solution domain with homogeneous properties, zonal properties, or randomly distributed hydraulic properties, and easy definition of boundary/initial conditions, and observation wells. In addition, a geostatistics package (GSLIB) is being implemented in the program to allow variogram analysis and estimation using kriging and cokriging for parameter estimations.

# *Applied Stochastic Subsurface Hydrology & Environmental Geophysics 2004:*

March 16 - 19, 2004

**Registration Form**

| | |
|---|---|
| Name: | Title: |
| Affiliation: | Occupation: |
| Address: | Degree: |
| | Discipline: |
| | Daytime Phone #: |
| | E-mail: |

Course cost is $2,000 per person. Payment should be made by check or money order, payable to:
**The University of Arizona, HWR Department.**

Deadline for registration is **February 12, 2004.** Bills for outstanding balance will be issued after **March 16, 2004.**

**To register: 1)** fill out this form and **2)** enclose a $100.00 US reservation deposit (payable to The University of Arizona, HWR Department), and **3)** mail registration to:

Dept. of Hydrology and Water Resources,
P.O. Box 210011,
The University of Arizona,
Tucson, AZ 85721-0011
***Attn: T.-C. Jim Yeh***